UNIVERSITY OF CALGARY

CREWES

Migration velocity analysis of incomplete/irregularly sampled data using least squares Kirchhoff migration

2011 CREWES
Sponsors' Meeting

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Outline

I. Review on Least Squares PreStack Kirchhoff Migration (LSPSM) for resolution & data reconstruction

II. Effect of velocity accuracy on LSPSM

III. Velocity analysis on LSPSM CIGs

IV. Summary

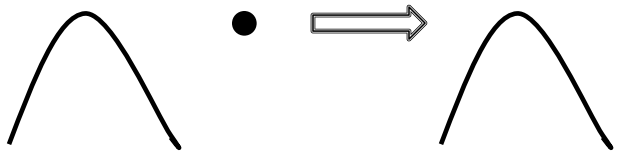
Kirchhoff Migration

- ✓ **Kirchhoff migration: handles incomplete/ irregular data.**

- ○ **Incomplete/spars data produces migration artifacts/acquisition footprints.**

Kirchhoff Migration

- **Modelling:** $Gm = d$



G **: Kirchhoff forward operator,**

m **: Reflectivity,**

d **: Real data.**

Kirchhoff Migration

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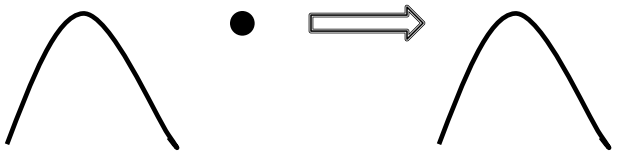
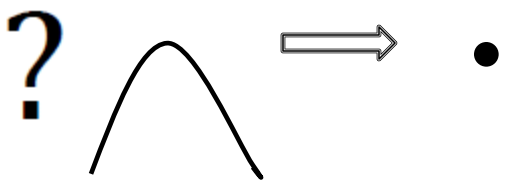


- **Inversion:** $G^{-1}d = m$



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Kirchhoff Migration

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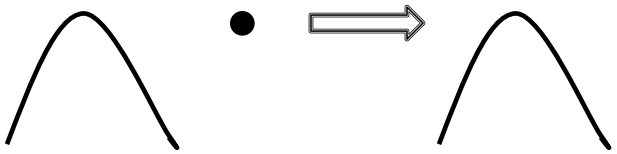

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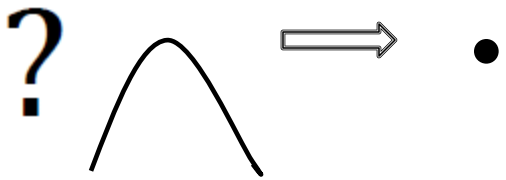
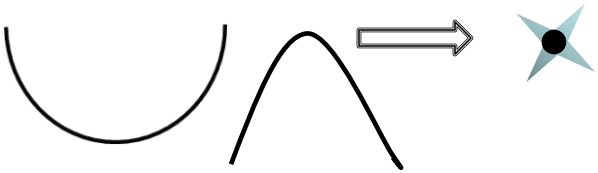


- **Migration:** $\boldsymbol{G^{T}d = \hat{m}}$



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Replacing Migration with LSPSM:

I. **Increase resolution:** attenuates migration artifacts.

II. **Data interpolation:** can reproduces missing data.

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LSPSM, how?

$$\boldsymbol{Gm} = \boldsymbol{d}$$ **(Modelling)**

$$\boldsymbol{G^T G\, m} = \boldsymbol{G^T d}$$

$$\boldsymbol{m} = (\boldsymbol{G^T G})^{-1} \boldsymbol{G^T d}$$ **(LSPSM)**

LSPSM, how?

$$\boldsymbol{Gm} = \boldsymbol{d}$$

$$\boldsymbol{G^T G\, m} = \boldsymbol{G^T d}$$

$$\boldsymbol{m} = (\boldsymbol{G^T G})^{-1}\boldsymbol{G^T d}$$

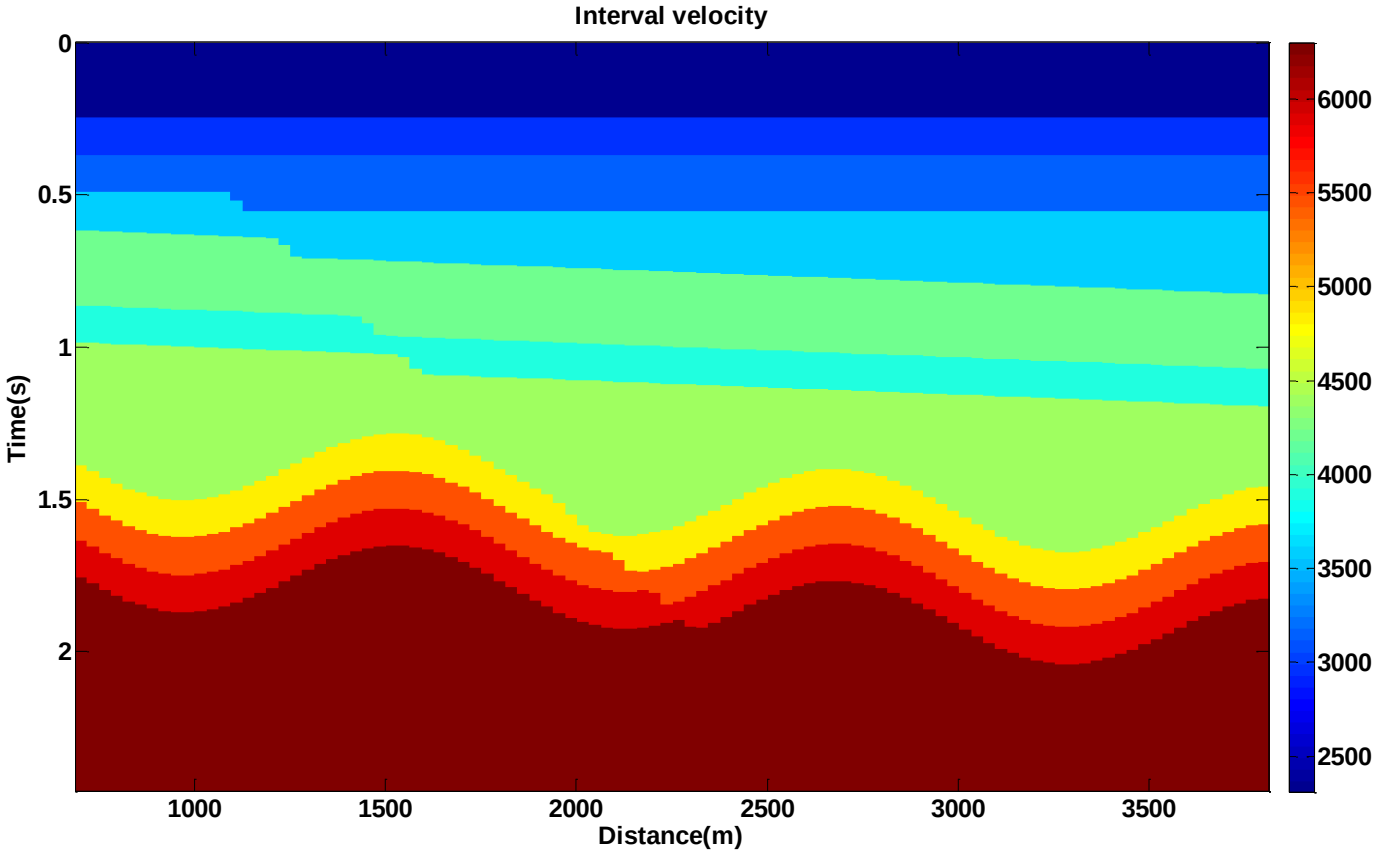
Damped:

$$\boldsymbol{m}_{DLS} = (\boldsymbol{G^T G} + \mu^2 \boldsymbol{I})^{-1}\boldsymbol{G^T d}$$

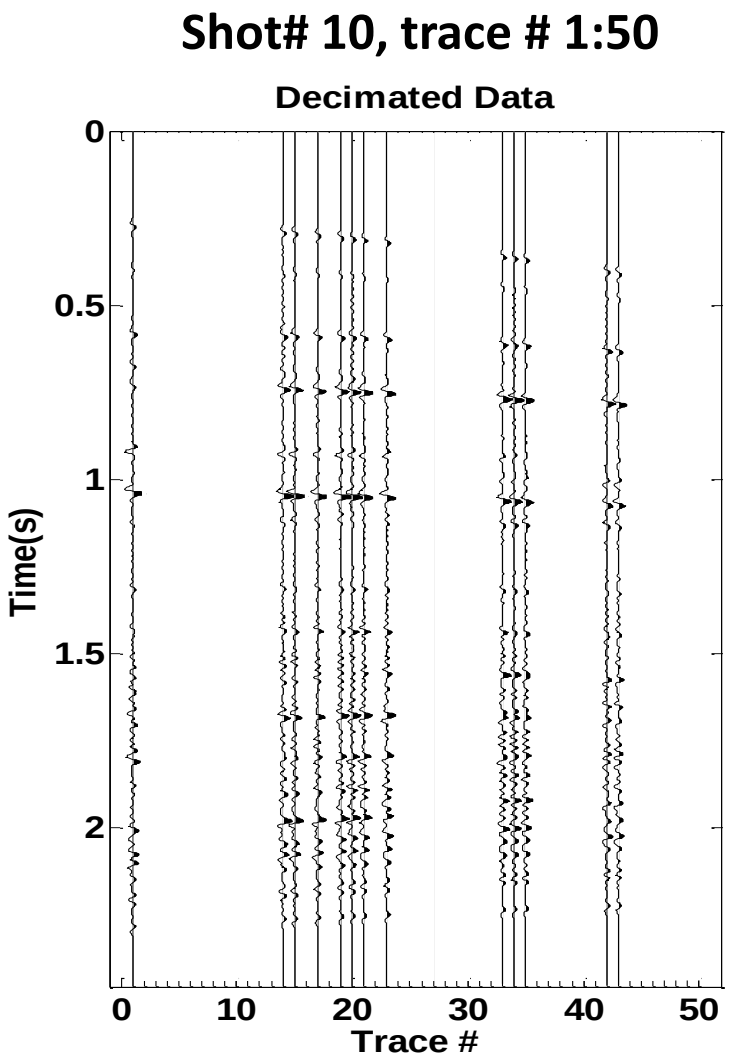
Nemeth et. al. (1999 ,2000) and Duquet et. al. (2000).

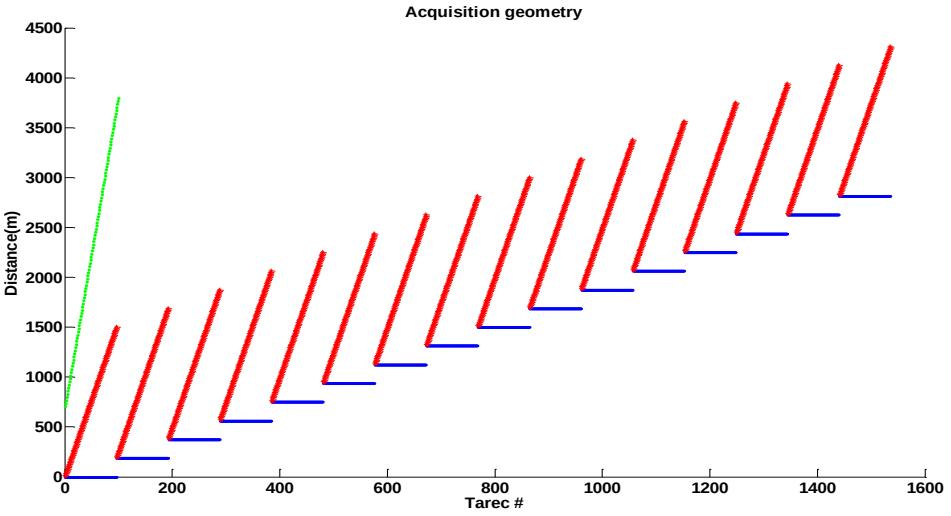
LSPSM for resolution, example:

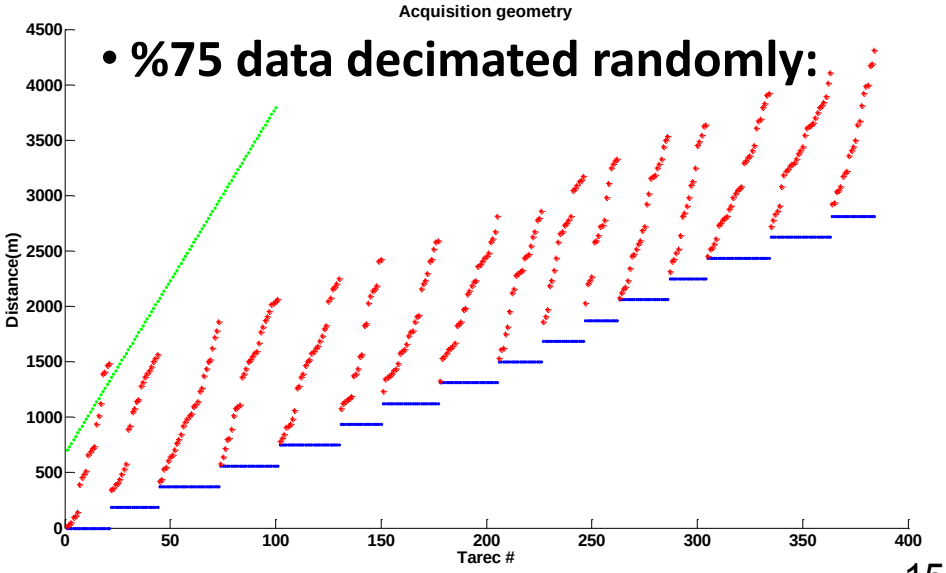
16 sources,
96 receivers/sources.
sampling rate: 2ms,
Fold: 4



LSPSM for resolution, example:



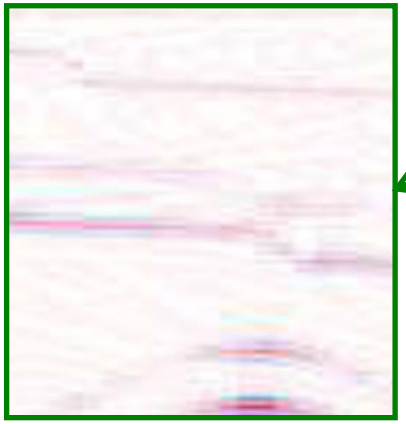


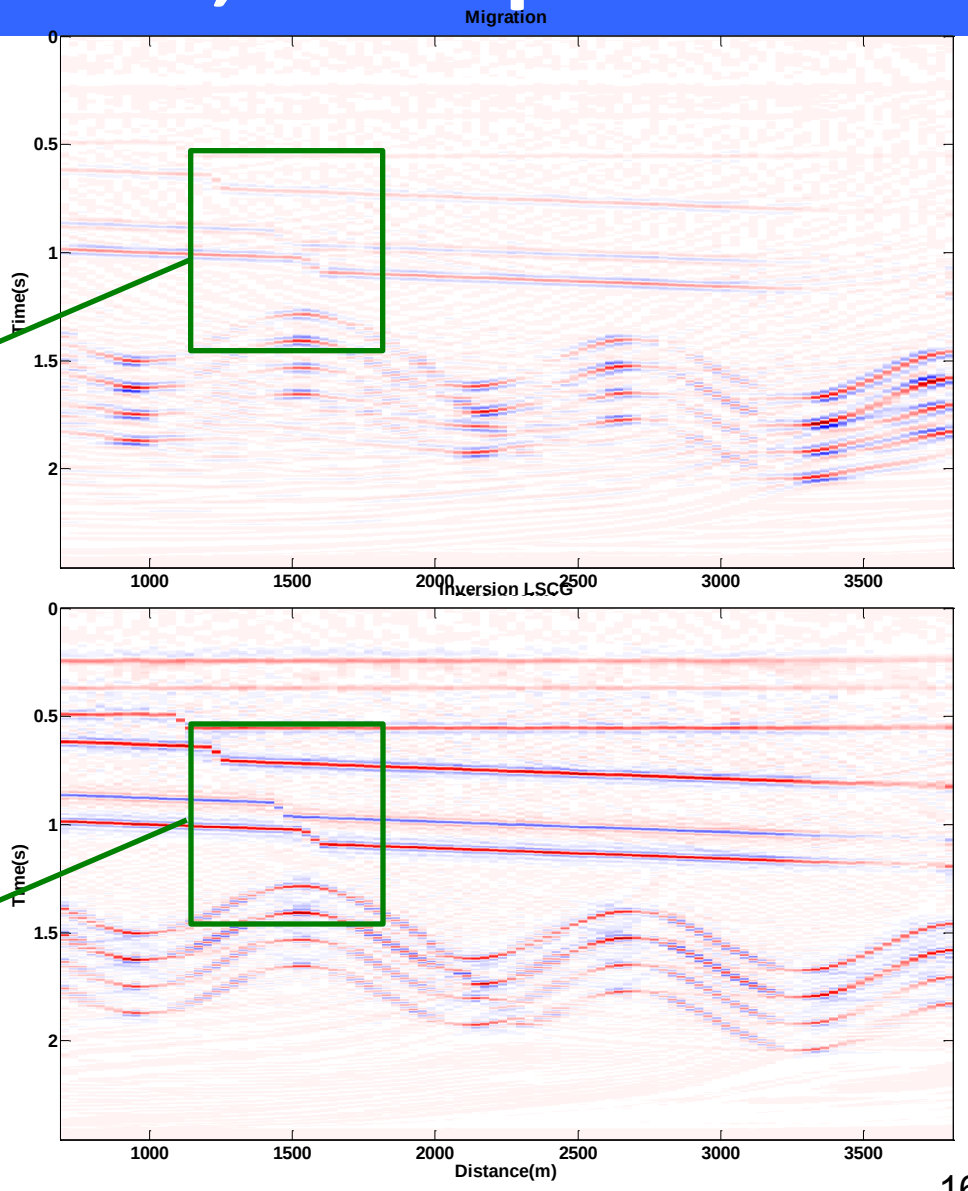


- %75 data decimated randomly:

LSPSM for resolution, example:

- **Migration:**





- **LSPSM:**

Increases resolution.

LSPSM: Reconstruction of prestack data

LSPSM can be used for data reconstruction,

$$\boldsymbol{m}_{DLS} = (\boldsymbol{G_i}^T \boldsymbol{G_i} + \mu^2 \boldsymbol{I})^{-1} \ \boldsymbol{G_i}^T \boldsymbol{d_i},$$

$\boldsymbol{G_i}$, $\boldsymbol{d_i}$ **: for incomplete data,**

LSPSM: Reconstruction of prestack data

LSPSM can be used for data reconstruction,

$$\boldsymbol{m}_{DLS} = (\boldsymbol{G_i}^T \boldsymbol{G_i} + \mu^2 \boldsymbol{I})^{-1} \ \boldsymbol{G_i}^T \boldsymbol{d_i},$$

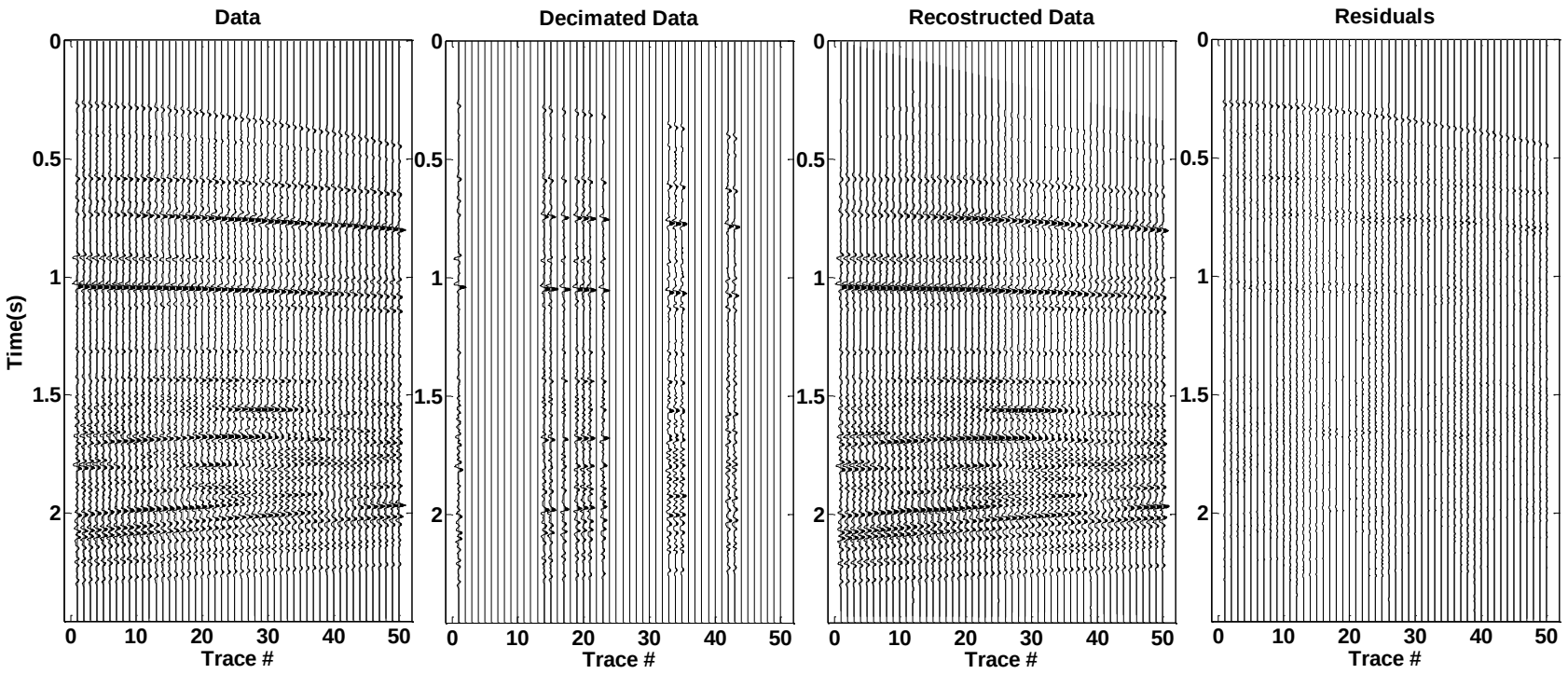
By modelling of the LSPSM image with the desired geometry:

$$\widehat{\boldsymbol{d}}_c = \boldsymbol{G}_c \boldsymbol{m}_{DSL} \ .$$

$\boldsymbol{G_i}, \boldsymbol{d_i}$: **for incomplete data,**
$\boldsymbol{G_c}, \widehat{\boldsymbol{d}}_c$: **for complete data.**

LSPSM for interpolation, example:

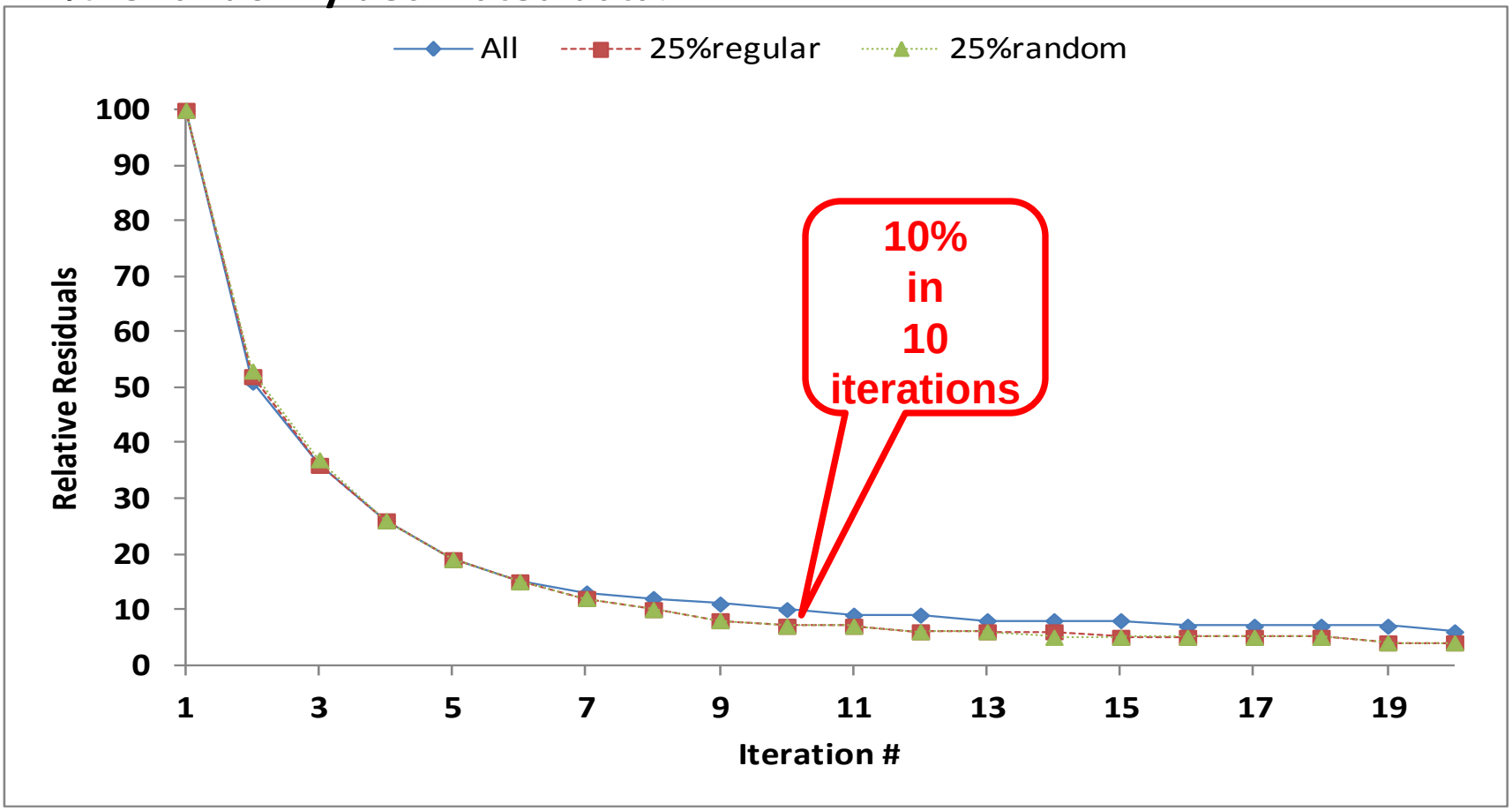
- **%75 data decimated randomly:**



Data **Decimated** **Reconstructed** **Residuals**

Convergence:

- All data,
- %75 regularly decimated data,
- %75 randomly decimated data.



LSPSM, Effect of velocity accuracy:

LSPSM handles data irregularities better than migration.

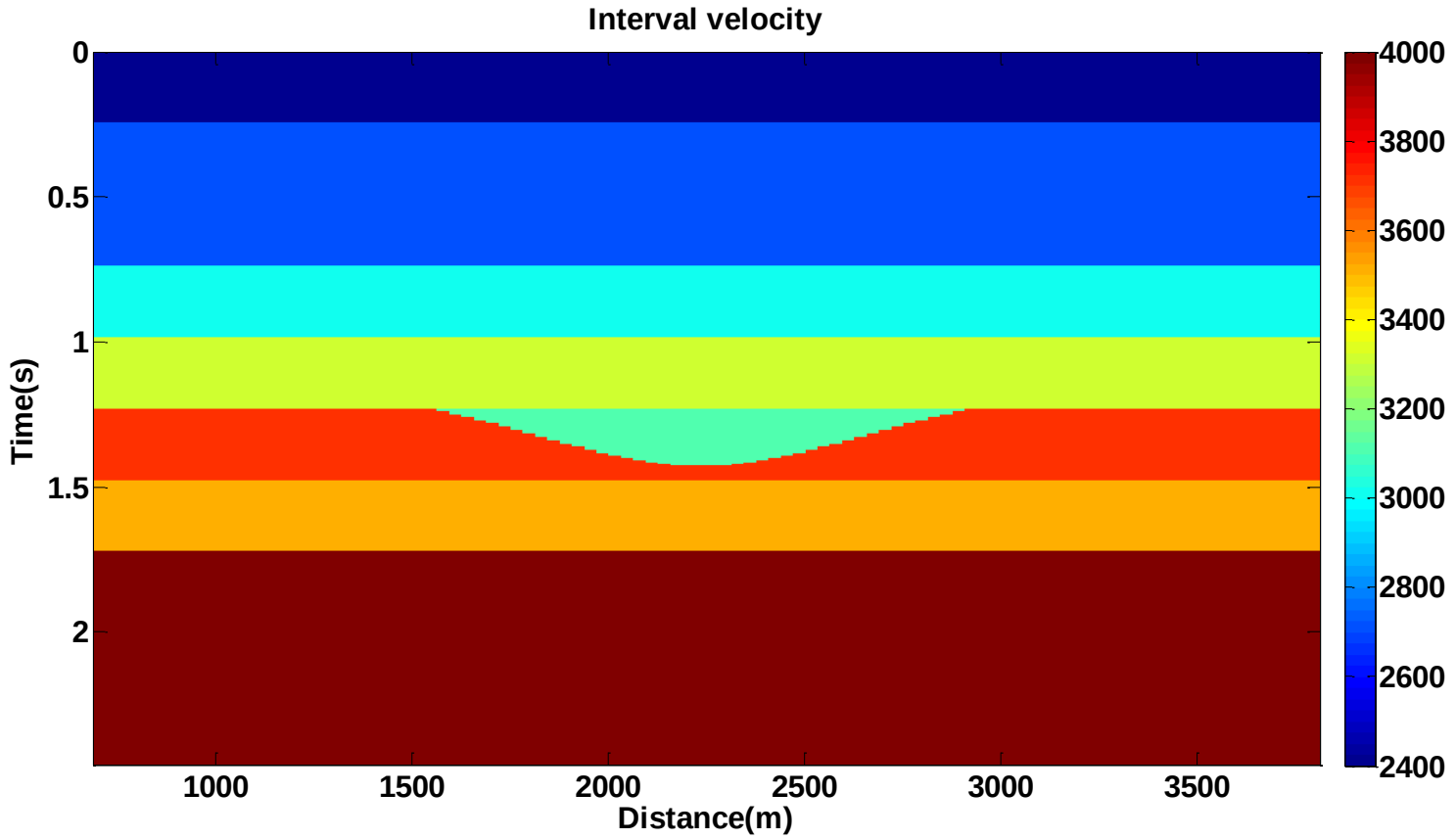
What about inaccuracy in velocity information?

1. **Focusing**
2. **Data reconstruction**
3. **Convergence**

Effect of velocity accuracy

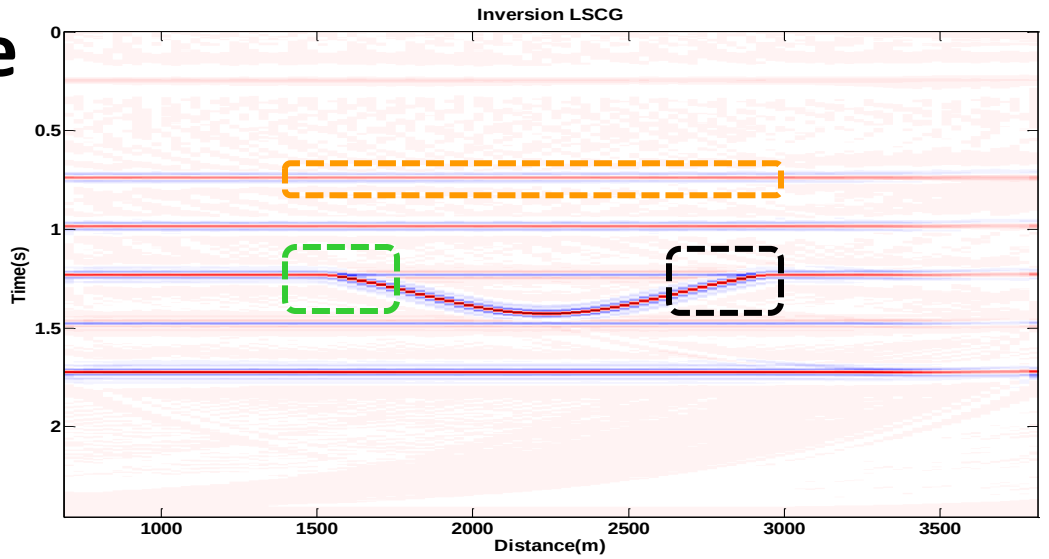
LSPSM require a relatively accurate velocity to return a high resolution image.

Lets choose another model:



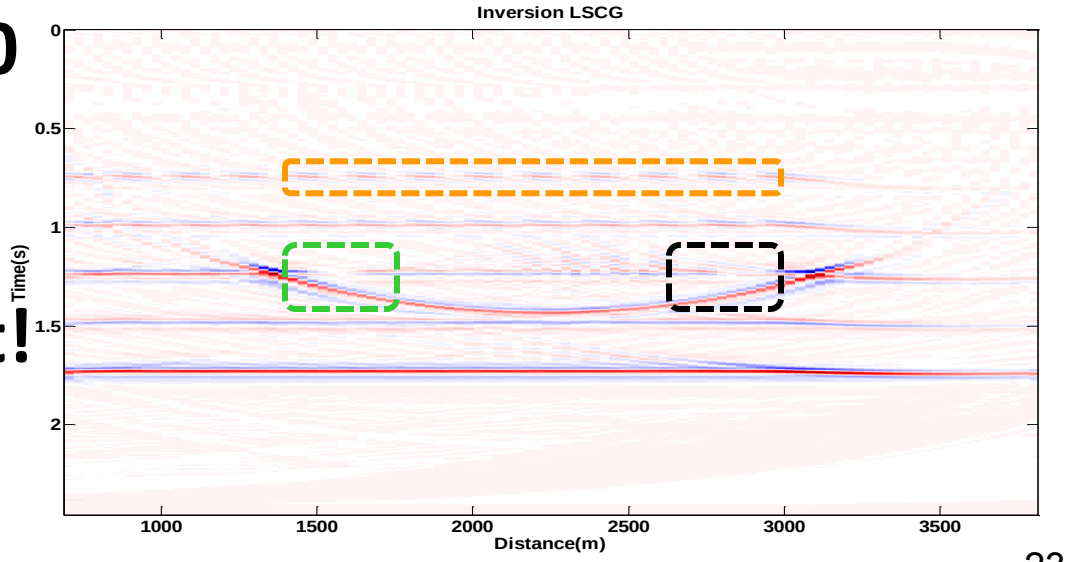
1. Effect of velocity accuracy on focusing

- **LSPSM with true velocity:**

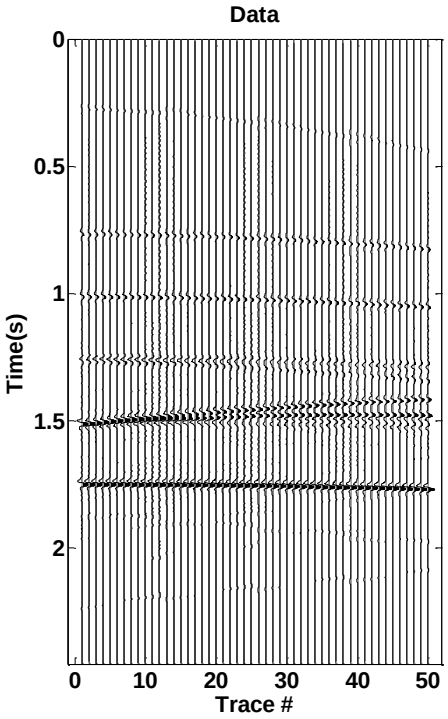


- **LSPSM with %10 higher velocity:**

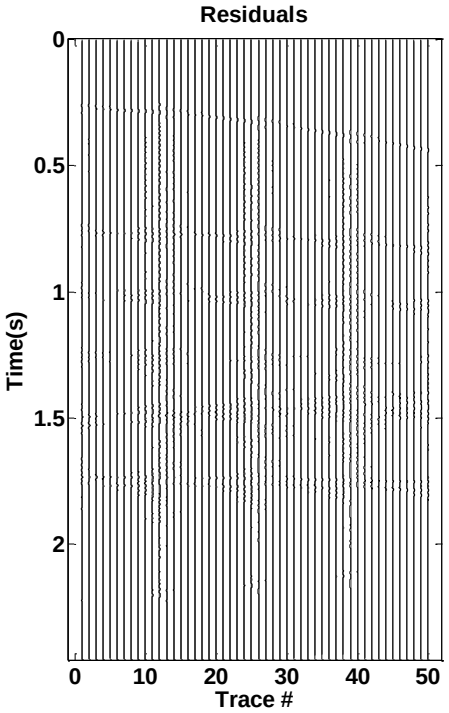
No improvement!



2. Velocity accuracy on interpolation



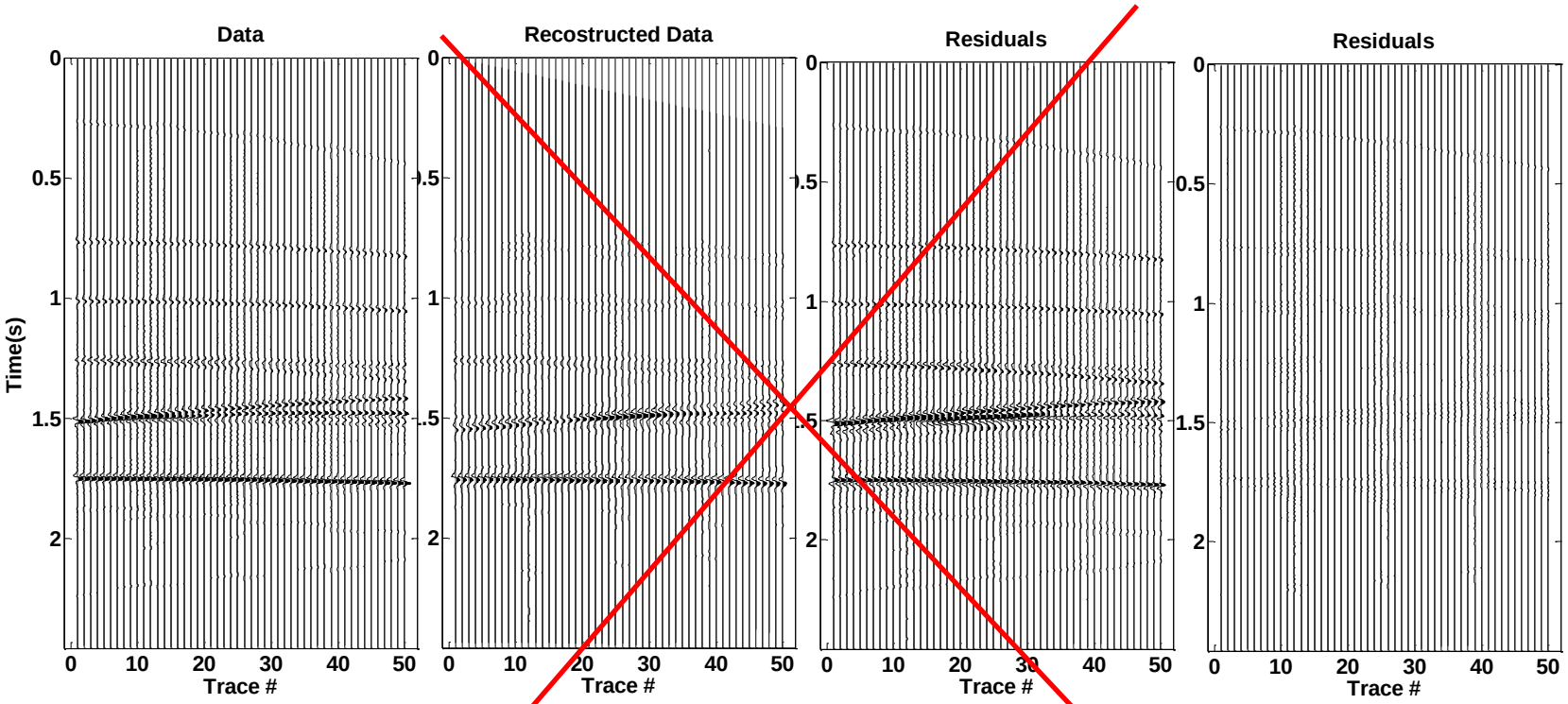
Data



Residuals

2. Velocity accuracy on interpolation

- **%10 higher velocity is used:**



Making lemonade!

- **Can we use LSPSM for velocity analysis of incomplete data?**

I. **Lower sensitivity to the incompleteness of the data.**

II. **Higher sensitivity to the accuracy of velocity.**

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Seismic velocity analysis:

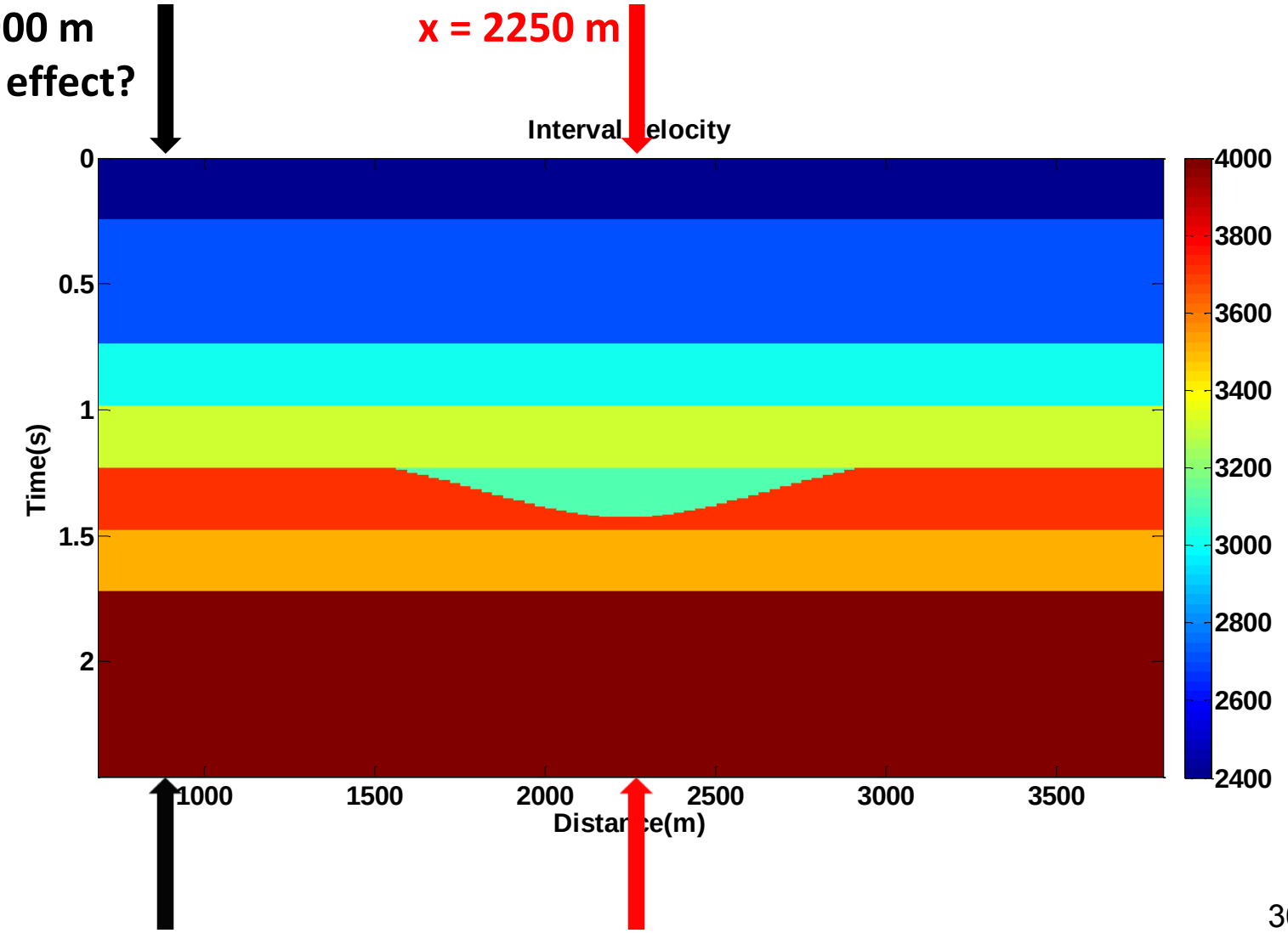
- **Velocity analysis on data domain, semblance method.**
- **Problem with dipping layer/complex geology.**
- **Velocity analysis on image (migration/LSPSM) domain can be used instead.**
  - **Offset domain CIGs**
  - **Shot domain CIGs**

Velocity analysis on shot domain CIGs:

1. **Constant velocity shot migration/ LSPSM**
   2000 : 25: 4500 m/s, 100 times.
2. **Semblance analysis on the CIGs.**
3. **Choosing best velocity at each time.**

- **Both prestack migration and LSPSM.**

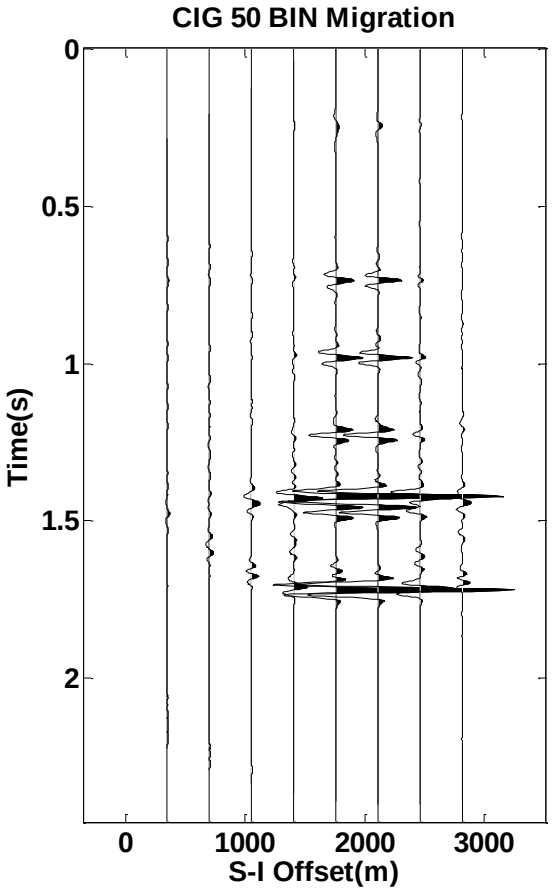
Velocity analysis, CIGs at 900 & 2250 m:



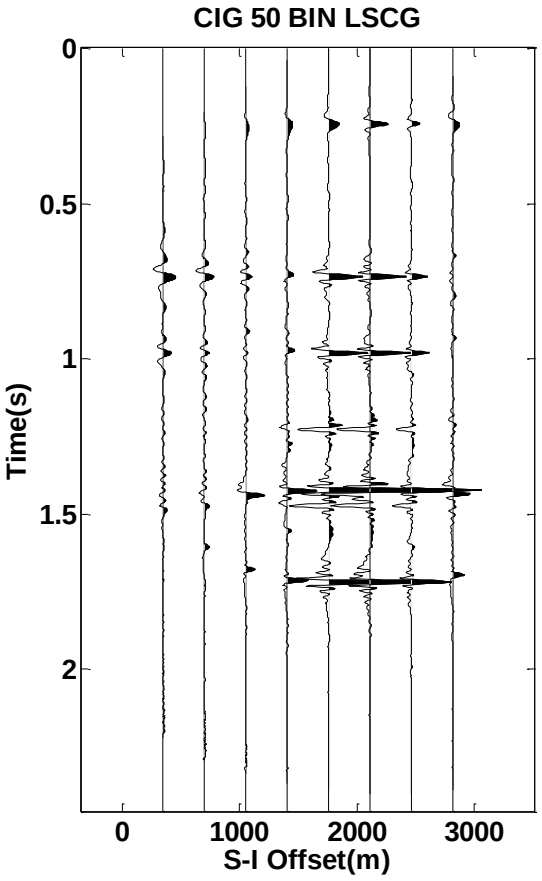
Velocity effect on shot domain CIGs:

Complete data, True velocity x = 2250 m

Migration



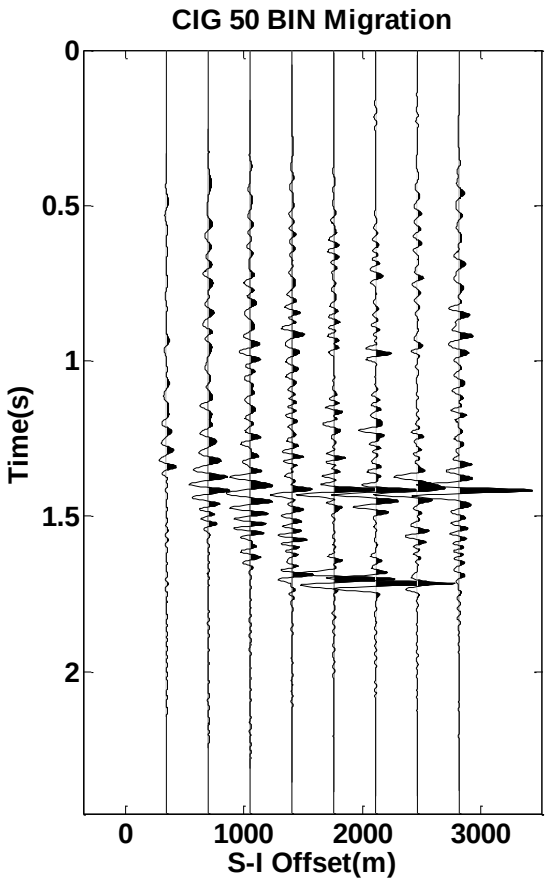
LSPSM



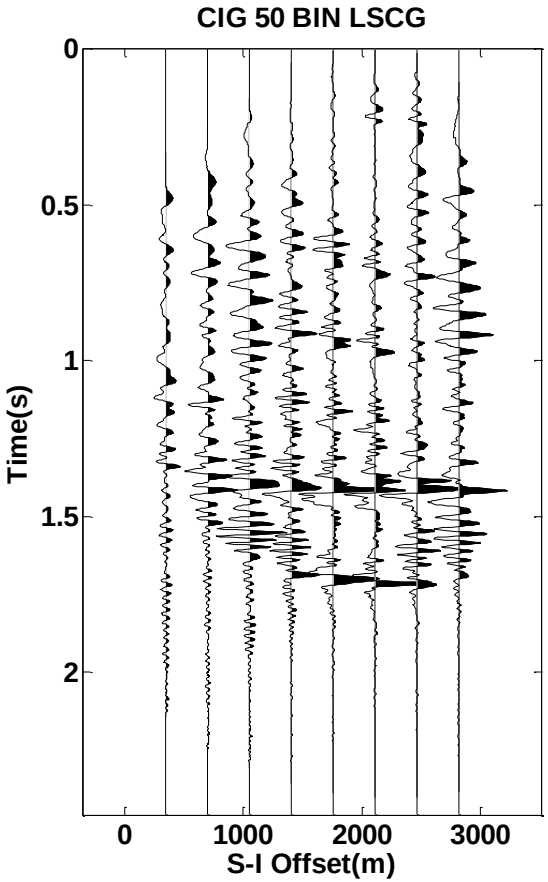
Velocity analysis on shot domain CIGs:

%10 of data, %10 Lower velocity x = 2250 m

Migration



LSPSM



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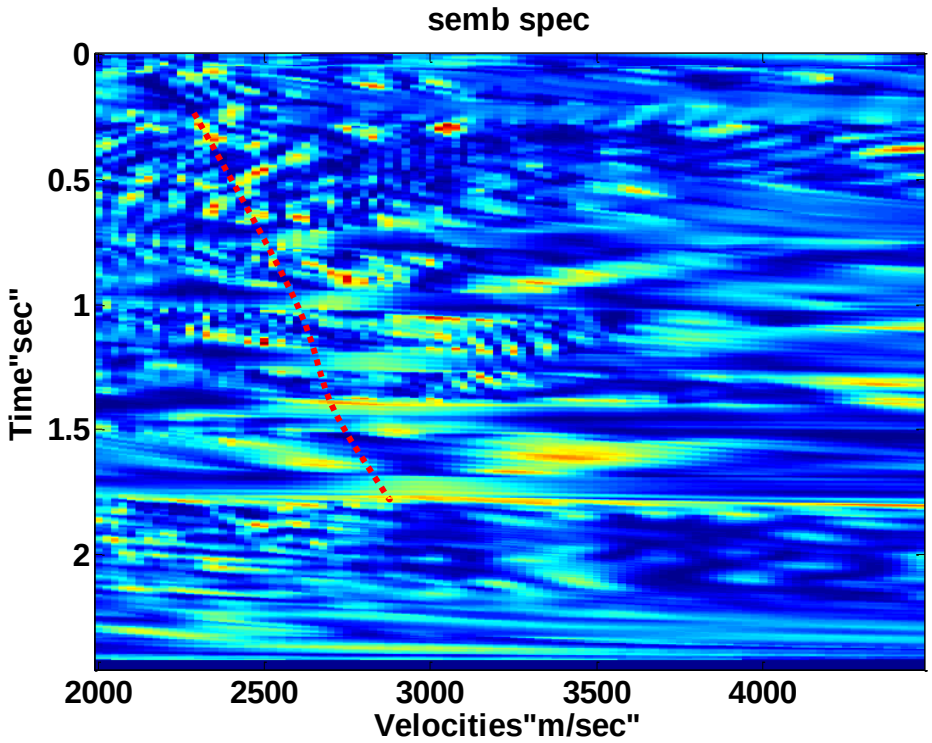
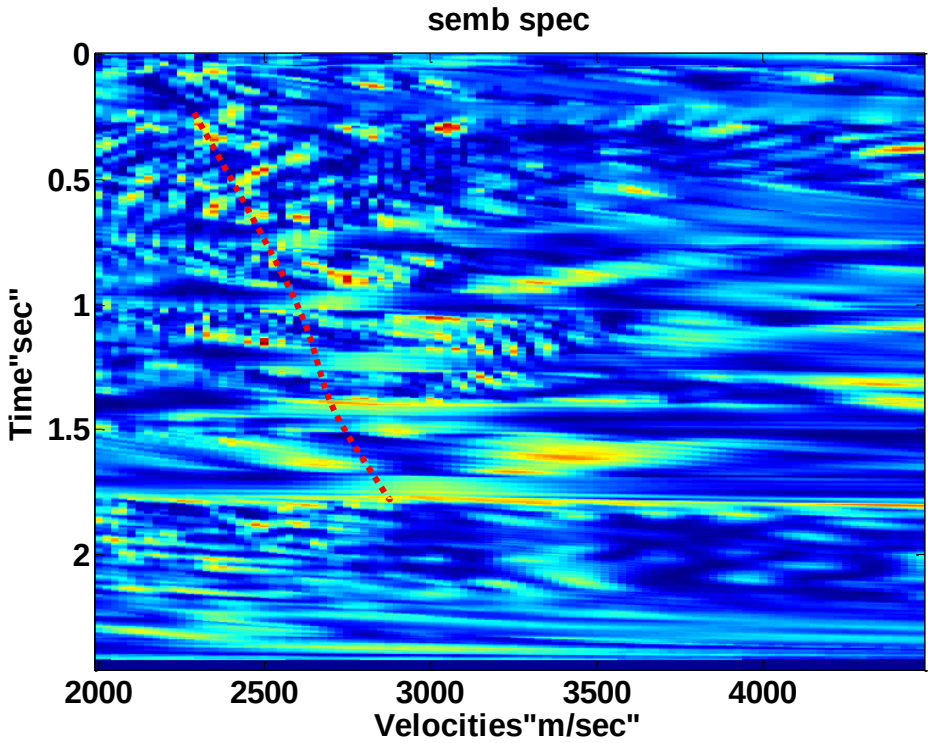


Semblance

- **Complete data, migration CIG Semblance**

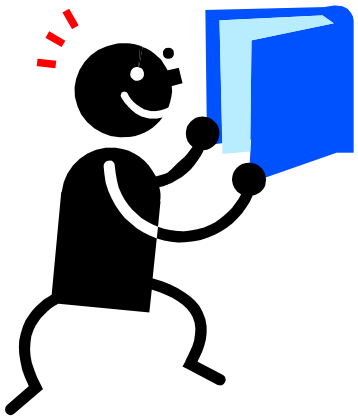
- **Velocity: 2000 : 25: 4500 m/s, 100 migration**
- **Number of bin = 8,**
- **CIG at x= 900m.**

Velocity analysis on shot domain CIGs:



?

Semblance



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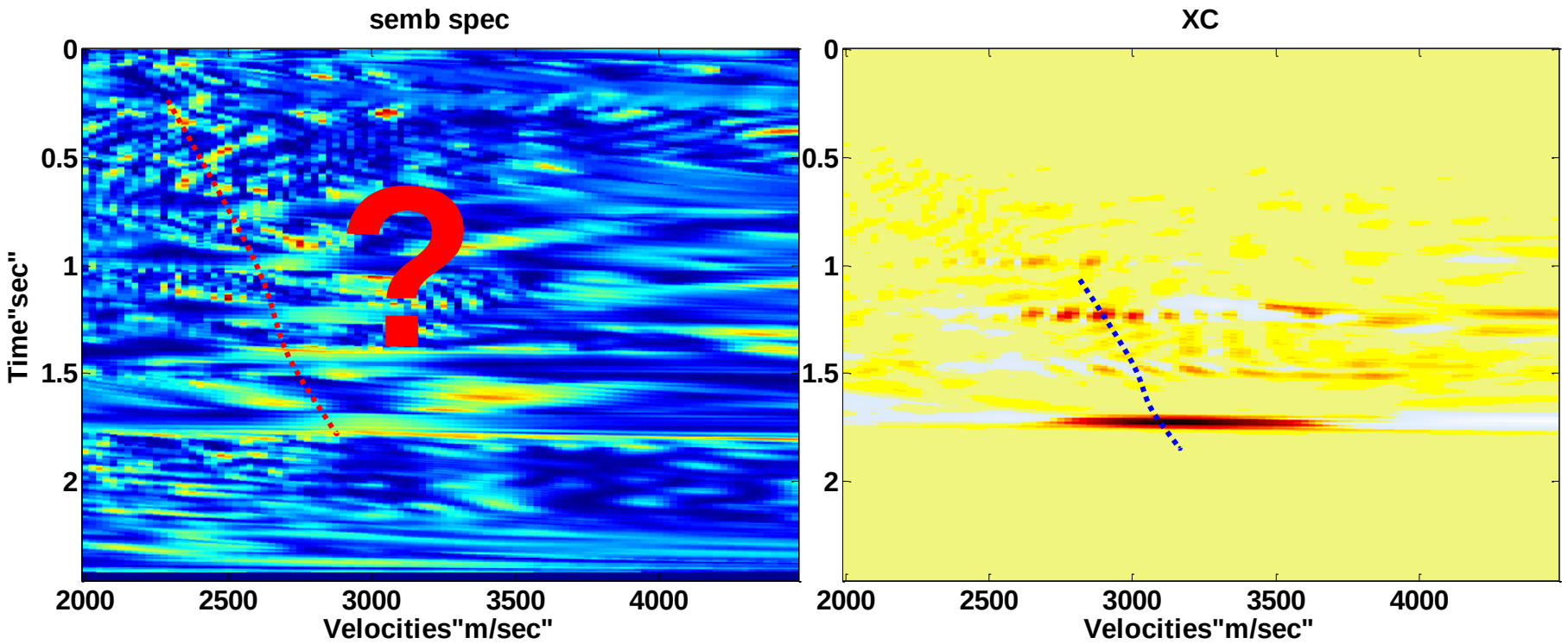
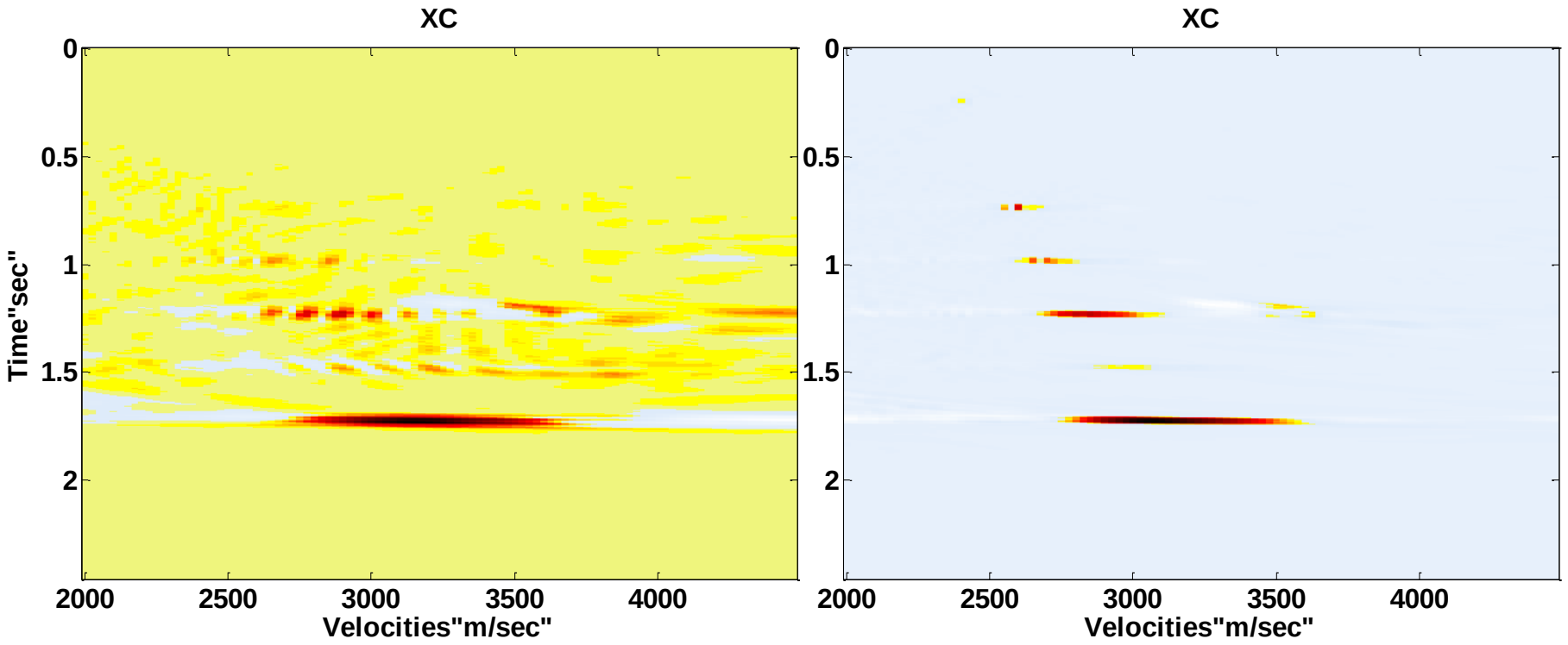


Semblance **Cross-correlation**

- Complete data, migration CIG Semblance and “unnormalized cross-correlation sum”
- Velocity: 2000 : 25: 4500 m/s, 100 migration
- Number of bin = 8,
- CIG at x= 900m.

Velocity analysis on shot domain CIGs:

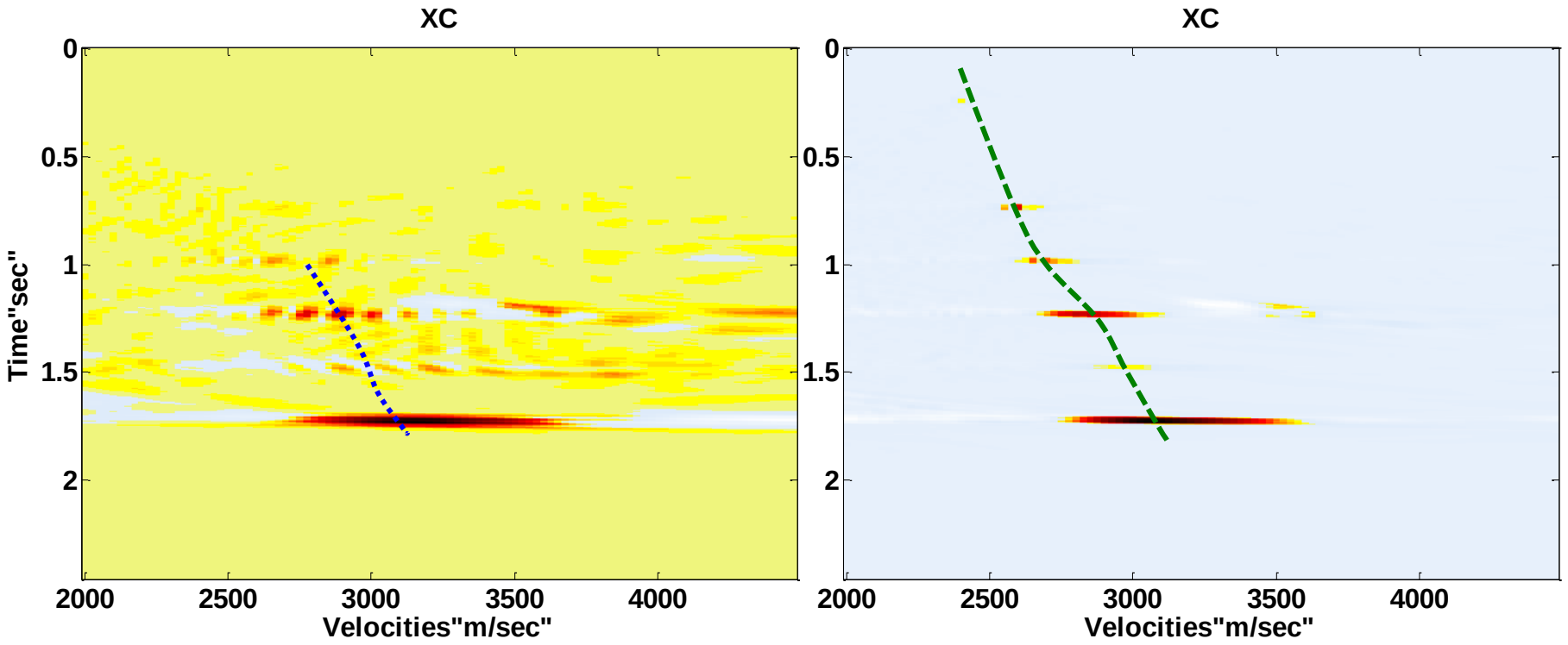


Migration **LSPSM**

%10 of data, CIG at x= 900m

Same color scale!

Velocity analysis on shot domain CIGs:



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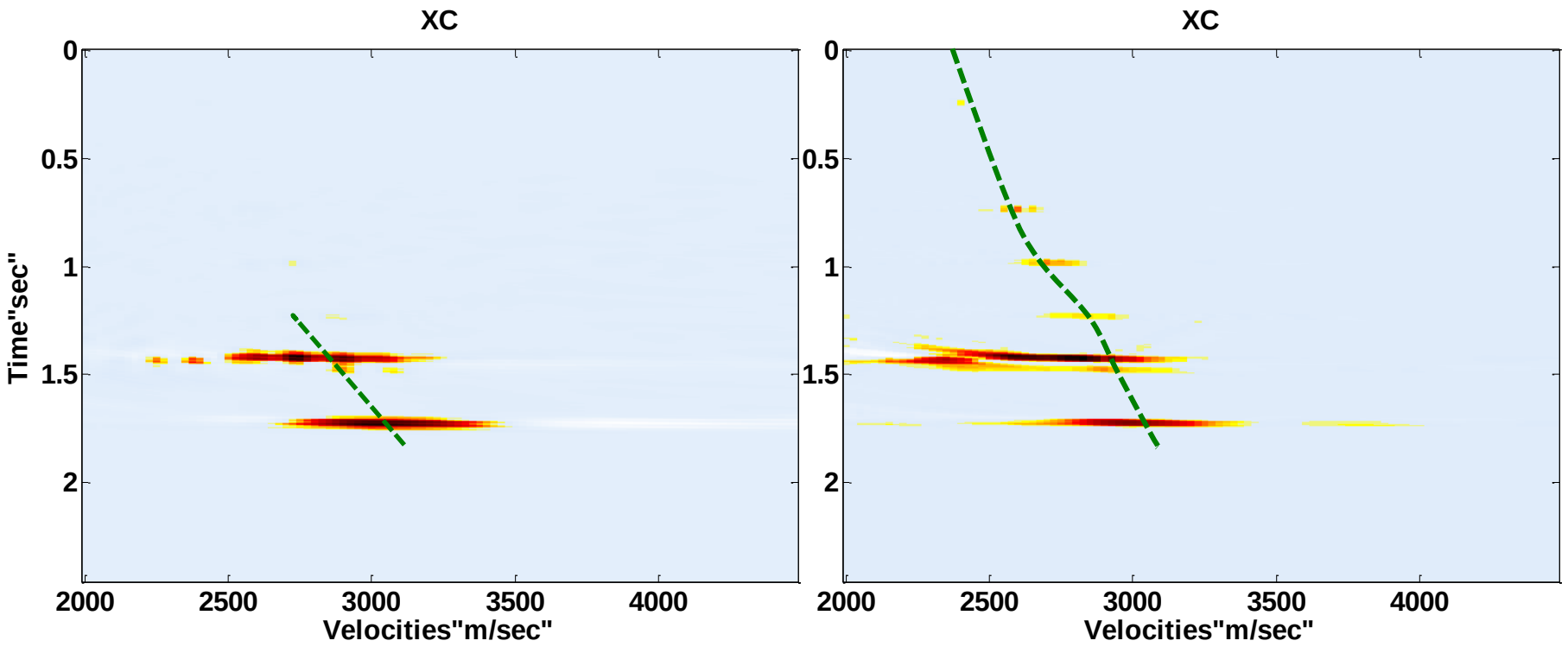


Migration **LSPSM**

%10 of data, CIG at x= 2250m

Velocity analysis on LSPSM CIGs:

Is the velocity extracted using this method reliable?

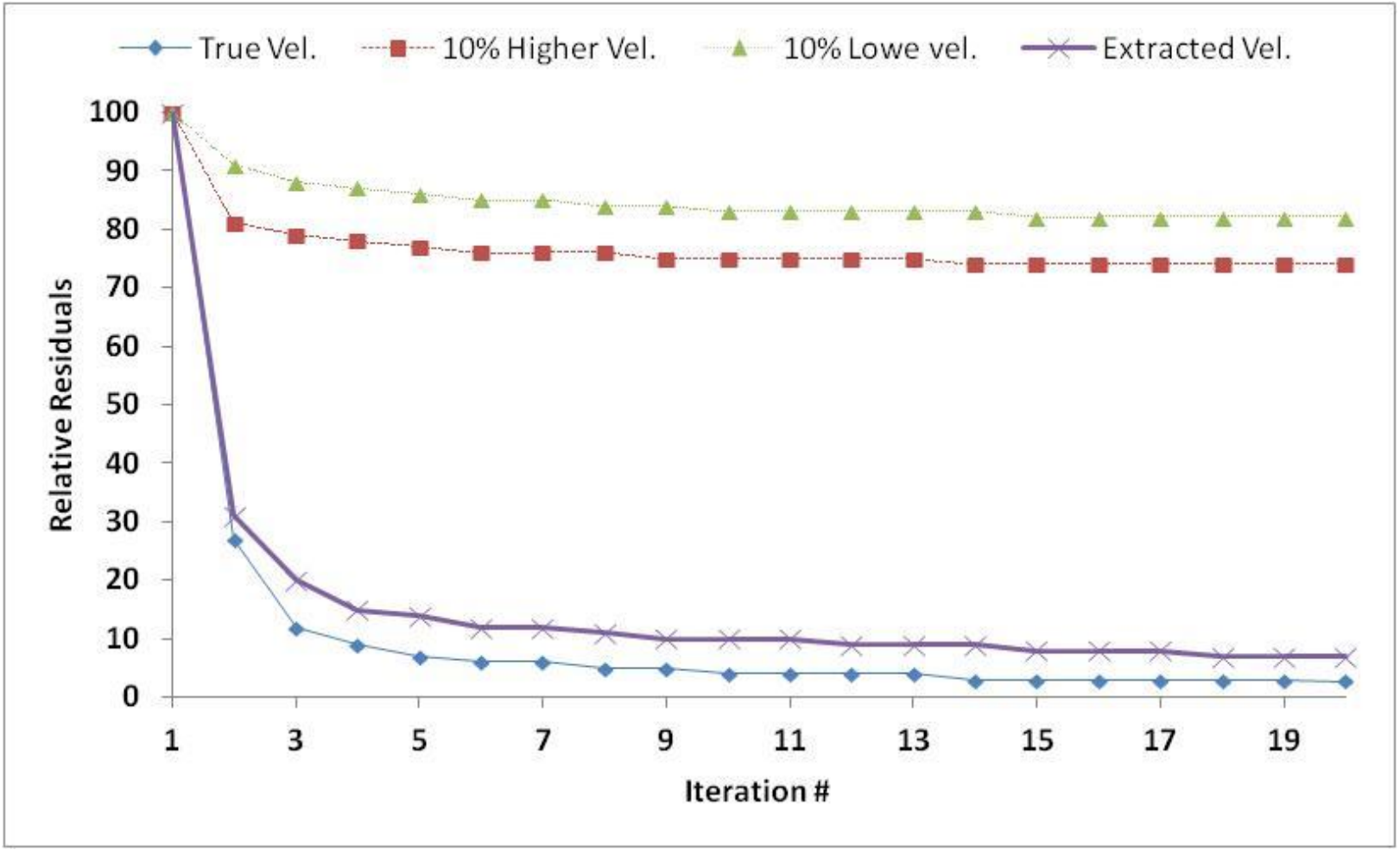
We suggested two tests:

1. **Convergence of LSCG.**

2. **Data reconstruction.**

Velocity analysis on LSPSM CIGs:

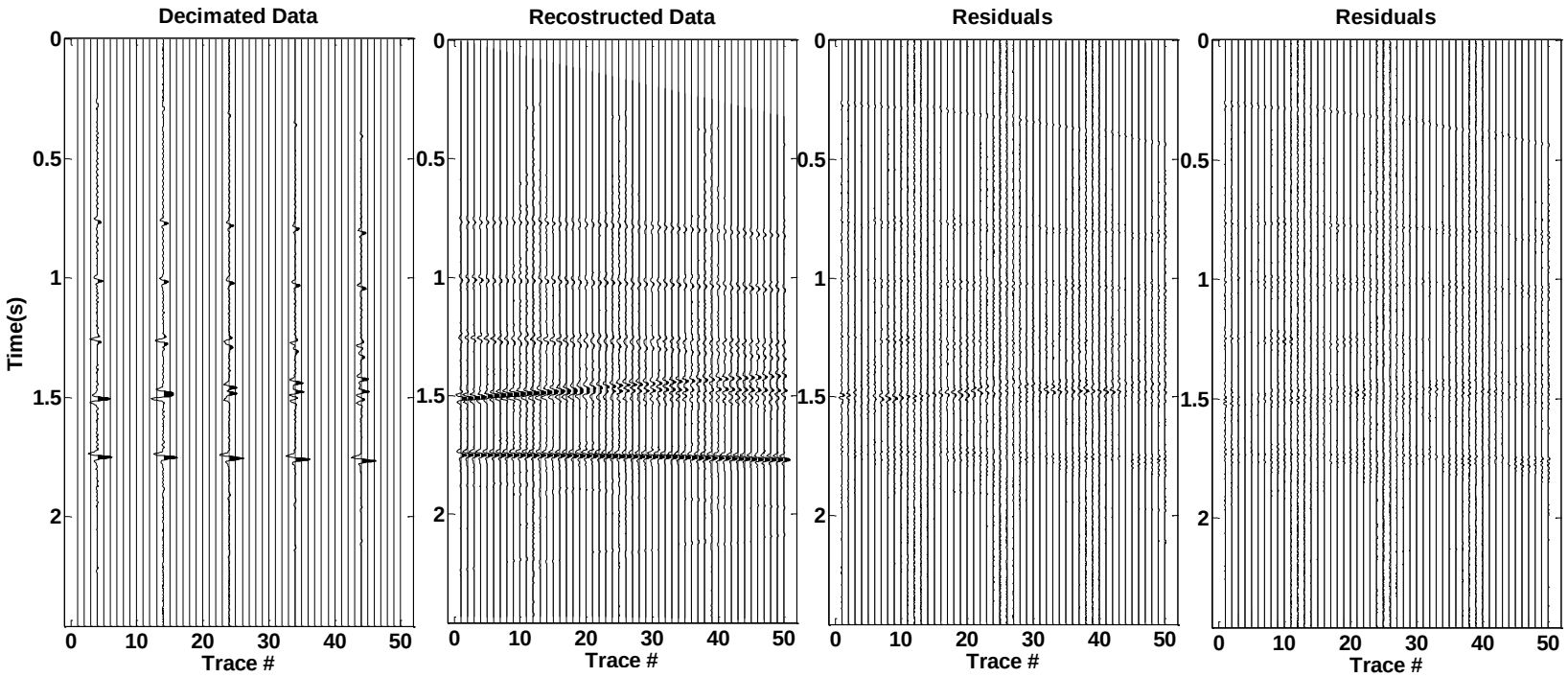
Is the extracted velocity reliable? Convergence:



Velocity analysis on LSPSM CIGs:

Is the extracted velocity reliable? Interpolation.

- %10 of data is used:



Decimated | **Reconstructed extracted vel.** | **Residuals extracted vel.** | **Residuals true vel.**

Summery:

- **LSPSM:**

  -Higher resolution image.
  -Accurate velocity estimation.
  -Data reconstruction.
  -Higher cost.

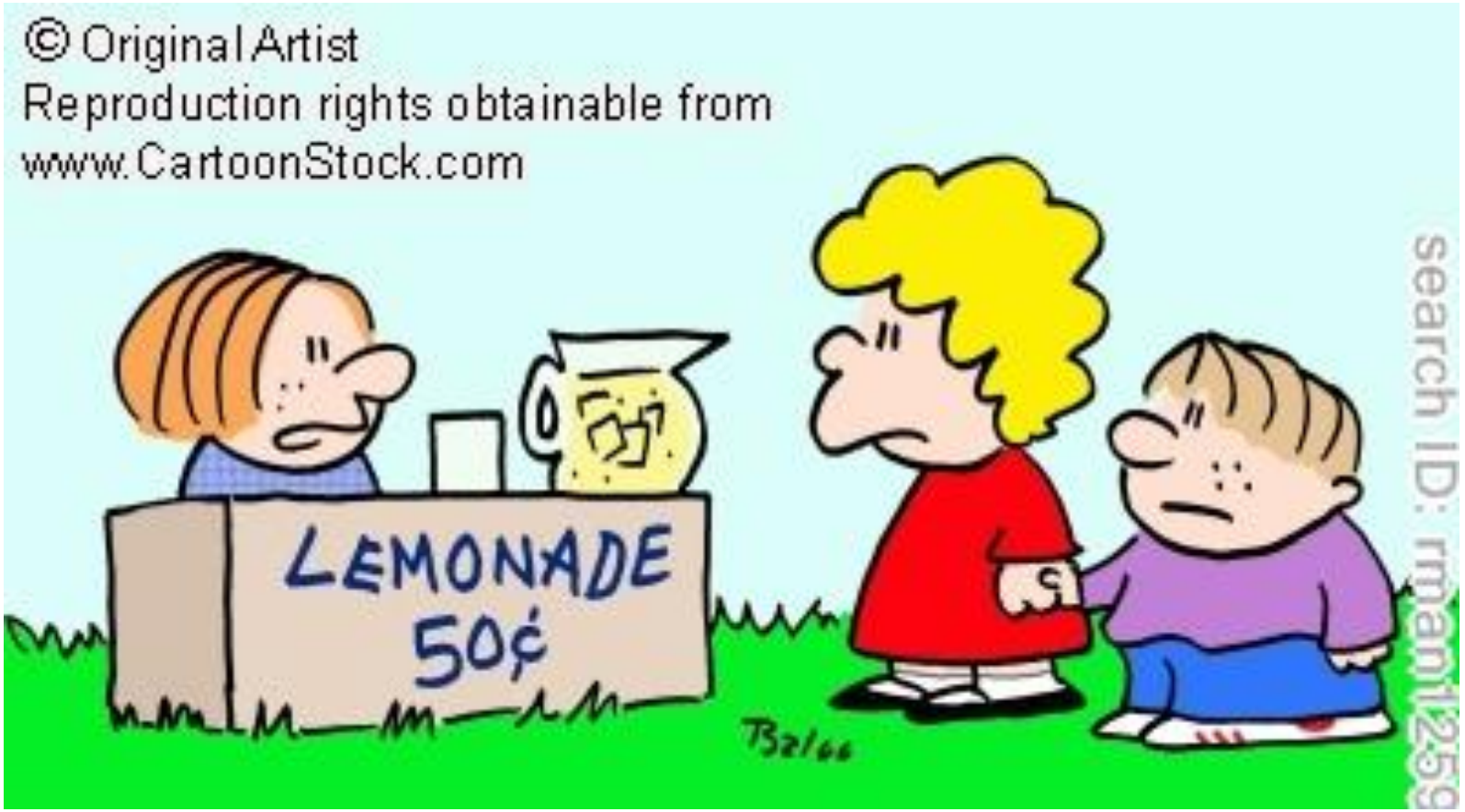
- **We extended velocity analysis on the CIGs to LSPSM.**

- **Better result when the data are irregular or incomplete.**

- **LSPSM data interpolation and LSCG convergence rate can be used for examining accuracy of the estimated velocity.**

Acknowledgment:

- I would like to thank:
  - Kevin Hall and Dr. Rolf Maier,
  - Dr. Helen Isaac, and Dr. Hugh D. Geiger,
  - NSERC and other CREWES sponsors,
  - Thank you.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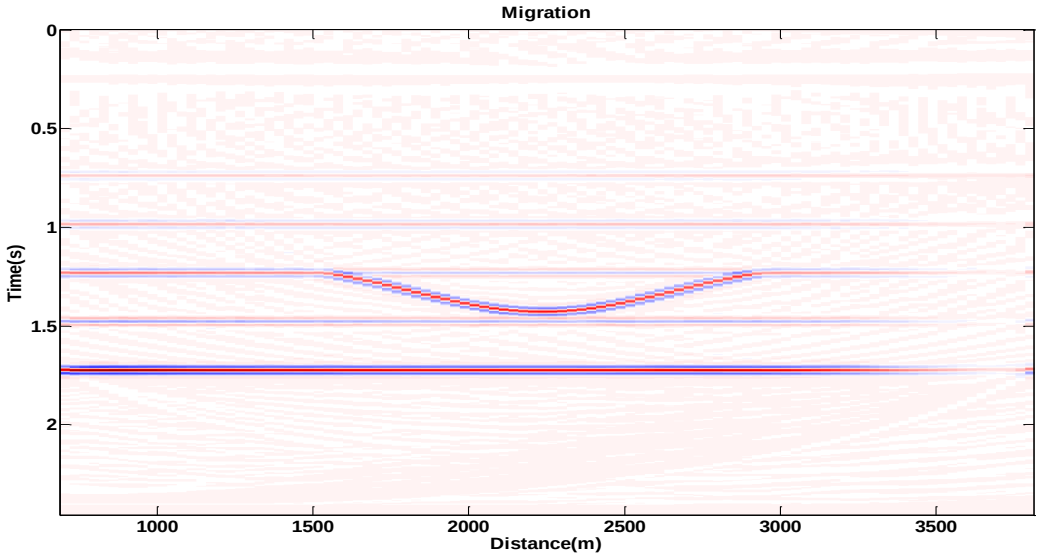
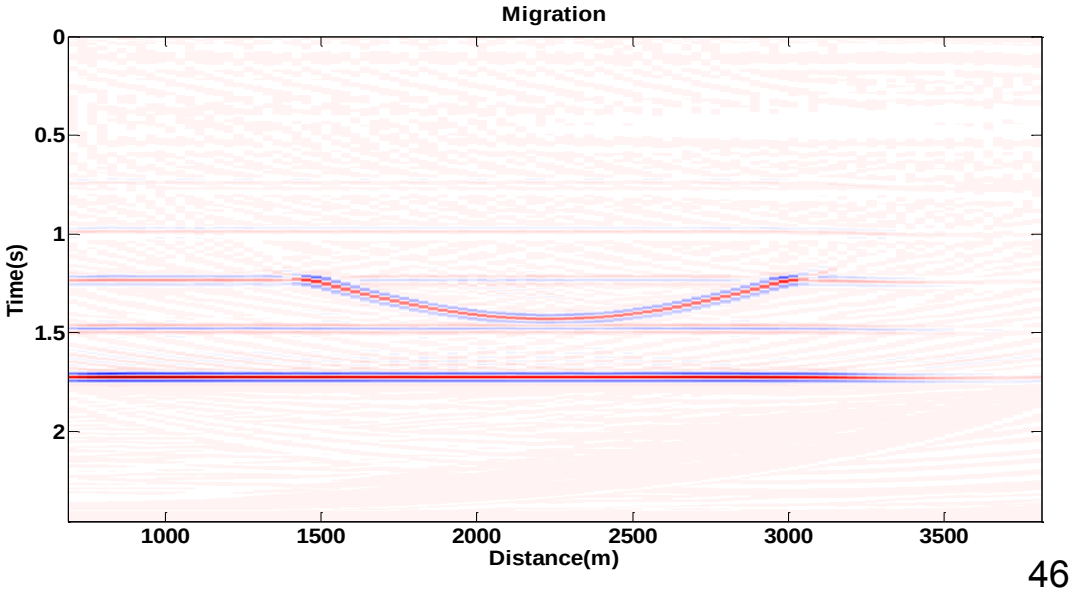
Effect of velocity accuracy on resolution

- **Migration with true velocity:**



- **Migration with %10 higher velocity:**

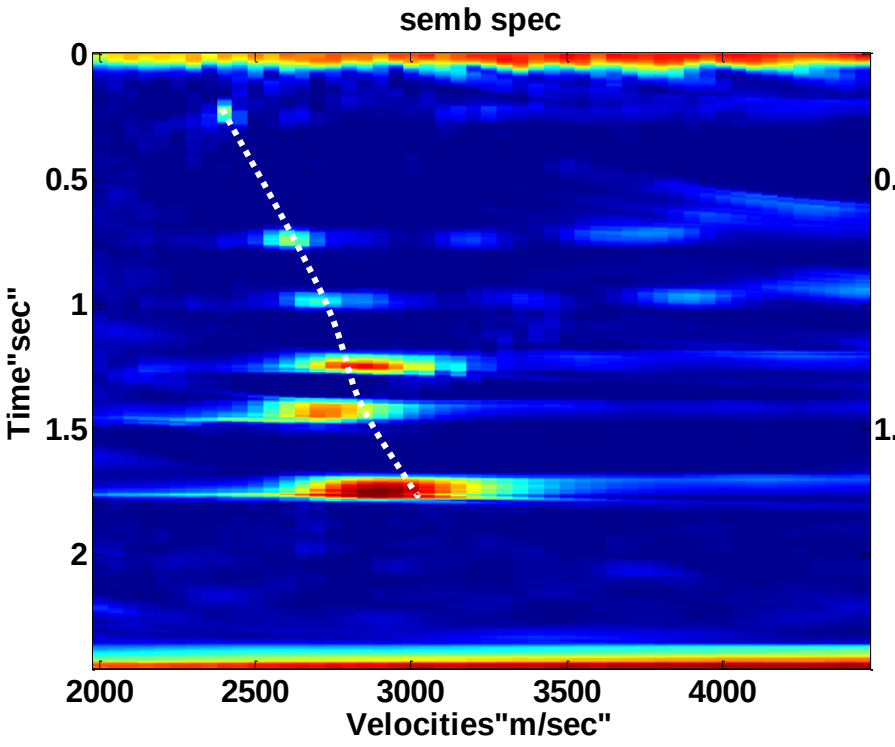


Velocity analysis on offset domain CIGs:

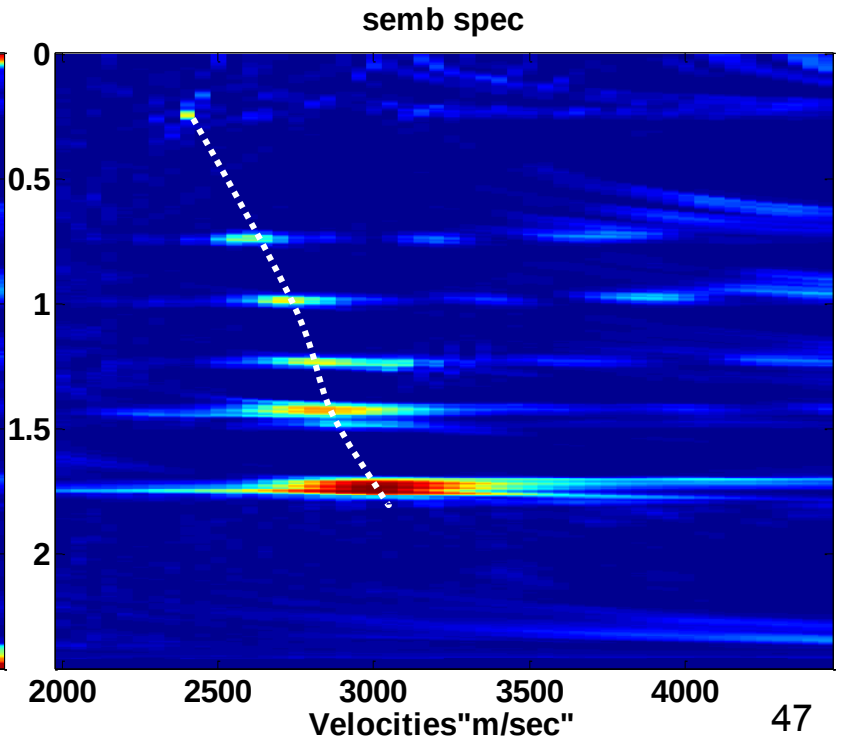
Velocity: 2000 : 50 : 4500 m/s, 50 migration/LSPSM
Number of offset bin = 20
CIG at x = 2250 m

Complete data

Migration



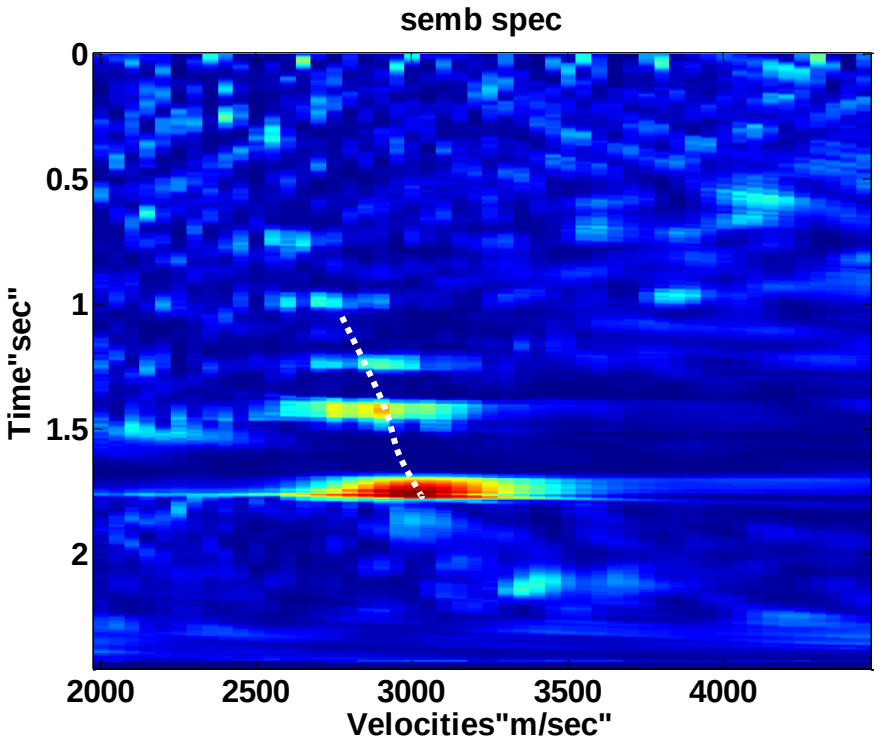
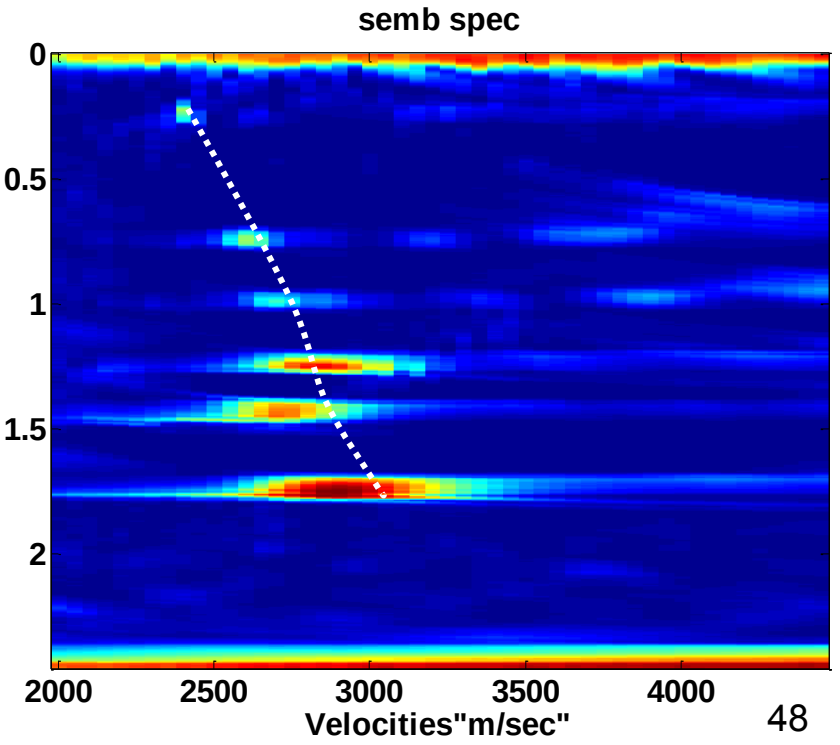
LSPSM



Velocity analysis on offset domain CIGs:

using only
%10 of data

Migration



LSPSM